

Measurement of neutron detection efficiency between 22 and 174 MeV using two different kinds of Pb-Scintillating fiber sampling calorimeters

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Abstract

We exposed a prototype of the lead-scintillating fiber KLOE calorimeter to neutron beam of 21, 46 and 174 MeV at The Svedberg Laboratory, Uppsala, to study its neutron detection efficiency. This has been found larger than what expected considering the scintillator thickness of the prototype. We show preliminary measurement carried out with a different prototype with a larger lead/fiber ratio, which proves the relevance of passive material to neutron detection efficiency in this kind of calorimeters.

Key words: KLOE, neutrons, efficiency, calorimetry

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Detection of neutrons with energies from a few to hundreds MeV is usually performed with organic scintillators, where the elastic scattering of neutrons on hydrogen atoms produces a visible response from recoil protons. Typical efficiency is $\approx 1\%$ per cm of scintillator thickness. The insertion of an organic scintillator in a high Z material, with a sizable cross section for elastic and inelastic neutron interactions, could originate a large production of secondary particles and consequently increase the detection efficiency.

The fine sampling lead-scintillating fiber KLOE calorimeter [1] has been primarily designed to detect low energy photons. During a study of kaon interactions in KLOE, a high efficiency for low energy neutrons was observed and then confirmed by the experiment simulation. To understand the underlying physical mechanisms which produce this difference, we planned a set of test beams to expose the calorimeter to dedicated neutron beams and we carried out a full simulation of the detector.

The KLOE calorimeter prototype used in this measurement is made of ~ 200 layers of 1 mm diameter blue scintillating fibers, glued inside grooved lead layers of 0.5 mm thickness. The final structure has a fiber:lead:glue volume ratio of 48:42:10 resulting in a density of $\sim 5 \text{ g/cm}^3$. The total external dimensions are $(13 \times 24 \times 65) \text{ cm}^3$, where the second value is the calorimeter depth and the third one is the fiber length. The calorimeter is readout at both fiber ends to reconstruct this coordinate by time

difference. The readout is organized in four planes in depth and three columns along the horizontal coordinate, originating cells of $(4.2 \times 4.2) \text{ cm}^2$. Larger readout elements are used in the rear part of the calorimeter. Each element is coupled to standard photomultipliers, PM's, through light guides. The PM signals are split to form the trigger with the coincidence of their discriminated analog sum for each side.

A reference counter was built with a 5 cm thick bulk of NE110 organic scintillator, of transversal dimensions $(10 \times 20) \text{ cm}^2$, by coupling it at the two ends to two EMI9814 PM's. To trigger on the scintillator, the PM signals were discriminated and an overlap coincidence was formed.

We have run our experiment at "The Svedberg Laboratory" (TSL) neutron beam facility [2], performing different test beams with high energy neutrons (174 MeV) in October 2006 and 2008 and low energy neutrons (21 and 46 MeV) in June 2007. The neutron energy spectrum is dominated by a peak at few MeV below the primary proton energy and a long tail down to thermal neutrons. Low intensity neutron beams of few kHz/cm² has been required to minimise the probability of double neutron counting. The neutron rate, R_n , has been measured by an Ionization-Chamber Monitor, ICM, with an absolute accuracy of 10% (20%) at high (low) energy. For a given trigger threshold, assuming full beam acceptance and no background, the efficiency of the detector to the overall neutron spectrum has been determined according to the formula: $\varepsilon = R_{\text{DAQ}} / (R_n \cdot F_{\text{live}})$, where R_{DAQ} is the acquired rate for the detector and F_{live} is the fraction of DAQ live time.

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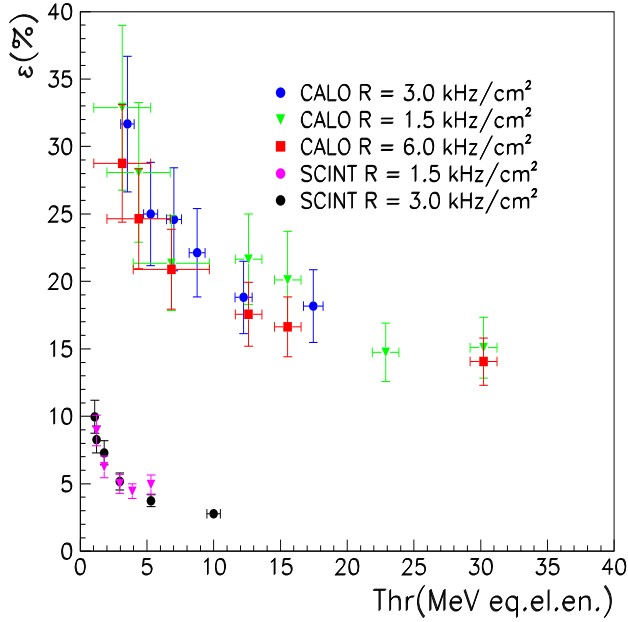


Figure 1: Dependence of ϵ_{calo} on the applied trigger threshold for run at 174 MeV. The scintillator efficiency obtained with the same data, after scaling to the calorimeter equivalent thickness, is also reported.

A detailed simulation of the calorimeter structure and of the experimental beam line has been done using FLUKA [3], which computes the energy deposits in the scintillating fibers, taking into account the signal saturation due to the Birks' law. A data-MC comparison of the neutron time of flight (ToF) distribution indicates a contamination of events coming from the area surrounding the collimator (halo). Its contamination is obtained by fitting the ToF data distribution with the expected signal shape from MC and the halo contribution. The halo shape is obtained both from the outer calorimeter cells and from dedicated runs with the calorimeter out of the beam line. The halo contamination is higher for events with low cell multiplicity, with an overall contribution of $\sim 30\%$ in the high energy runs. This fraction is smaller for low energy neutron beams, in agreement with the measurements carried on with a fission monitor counter used for the absolute calibration of the beam flux, which provide a correction factor of 0.80 ± 0.13 .

To evaluate the neutron detection efficiency, each cell is calibrated with minimum ionising particles (MIPs). The ratios between data energy distributions at different threshold levels have been used to determine the cut-off introduced by the trigger. After applying the beam halo correction, the calorimeter neutron detection efficiency ranges between 30% at high energy (Fig. 1) and 50% for low energy runs. The errors on vertical scale are dominated by halo subtraction and absolute neutron flux, while on the horizontal scale a conservative error has been assigned. For comparison, the efficiency of the 5 cm thick NE110 scintillator ranges from 4% to 10% for values of the trigger threshold below 5 MeV of electron equivalent energy, in good agreement with the available measurements in literature.

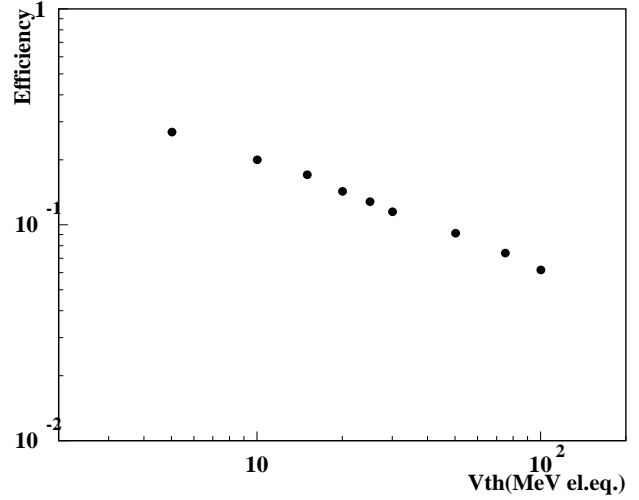


Figure 2: Efficiency of proto-2 detector as a function of the threshold.

This indicates that the measured calorimeter efficiency is sizeably enhanced with respect to the expected 8–10% based on the amount of scintillator only.

A second lead scintillating fiber calorimeter prototype, proto-2, has been tested with 174 MeV neutrons at TSL in October 2008. This prototype, 32 cm in length and (7.5×7.5) cm² in cross section, has a different structure, with fibers at the vertices of squares, and a resulting structure with lower fiber/absorber ratio than KLOE: fibers/total volume is 19.5%. At each module end, the fibers are grouped together in two bundles that are directly connected to PM's. The trigger requires an analog sum of the two signals from each module end larger than a given threshold V_{th} .

The efficiency has been evaluated at different V_{th} values with the same technique described before. The contribution of the halo neutrons, of the order of 10%, is subtracted to the rate. The trigger threshold V_{th} is converted in units of MeV equivalent energy by using the response of the detector to minimum ionizing particles and the quantity (e/MIP) given in Ref. [4] for calorimeters having the same fiber/absorber ratio. Fig. 2 show the preliminary neutron efficiencies of proto-2 as a function of V_{th} . The neutron detection efficiency is comparable with that of the KLOE-like calorimeter, which has a larger fiber/absorber ratio but similar lead amount. This shows that the fraction (or the absolute quantity) of passive absorber plays an important role. If we compare the efficiency parametrizing it per unit of scintillator thickness we get 3%/cm and 13%/cm for KLOE prototype and proto-2 respectively, which indicates a large efficiency enhancement for denser calorimeters.

References

- [1] The KLOE collaboration, NIM A 482 (2002) 364-386.
- [2] A. V. Prokofiev et al., PoS (FNDA2006) 016 (2006).
- [3] A. Fassò et al., CERN 2005-10, INFN/TC_05/11, SLAC-R-773.
- [4] R. Wigmans, "Calorimetry: Energy measurement in Particle Physics", Oxford University Press.